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Fly Ash an Alternative of Clay in Bricks: A Sustainable Solution for Future Constructions

Talha Mumtaz[1], Qasim Shaukat Khan*[1], Muhammad Hassan Javed[1], Asad U. Qazi[1]

[1]*University of Engineering and Technology, Lahore, Pakistan*
*Corresponding author/ E-mail: qasimkhan@uet.edu.pk

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ABSTRACT. *Clay (CL) bricks have been commonly used in construction industry for centuries. The negative environmental impacts of use of CL bricks include rapidly depleting fertile clayey layer of soil and the high energy consumption of CL bricks, which have led to the development of alternative brick units incorporating waste materials. Fly ash (FA) brick has been identified as a sustainable and environmental friendly alternative of traditional CL brick, which reduces carbon dioxide (CO_2) emissions and hence global warming. This study aims to develop eco-friendly geopolymer mortar brick mixes using FA and CL without heat curing and applying molding pressure. This study investigates influences of percentage replacements of CL with FA and curing period on the compressive strength (CS) of geopolymer mortar brick mixes. In the preparation of geopolymer mortar mixes, the percentage replacements of CL with FA varied from 0 to 100% (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%) using 12 M sodium hydroxide (NaOH) solution. A total of 11 geopolymer mortar mixes were cast and cured at 14, 28, 56 and 90 days. The optimum CS of 49.7 MPa with 80% replacement of CL with FA using 12 M NaOH solution at 90 days was achieved. This study is expected to contribute in reducing the level of CO_2 emissions, which will subsequently reduce global warming and smog formation in Pakistan*

Keywords: Fly Ash, clay, NaOH molarity, compressive strength

1. INTRODUCTION

The clay (CL) bricks have been widely used as a building unit since ancient times because of their high durability and cost effectiveness [1]. CL bricks are made by mixing CL and water, which is then poured in molds to attain the desired shape and are burnt at temperatures of about 1000 to 1500 °C in brick kilns [2]. The burning of CL bricks releases harmful gases such as CO_2, carbon monoxide and particulate matter (PM 2.5) [3]. The global annual productions of burnt CL bricks have reached 1.5 trillion while in Asia burnt CL bricks reached 1.35 trillion per year [4]. Pakistan is the third largest producer of burnt CL bricks in South Asia with 45 billion burnt CL bricks produced per year [5]. The large emissions of CO_2 associated with production of burnt CL bricks leads to global warming, which results in rapid melting of glaciers, sporadic heat waves, devastating floods, food scarcity, soil erosion and deforestation.

FA is a by-product of coal power plants (CPP). In construction industry, FA is used as an alternative of CL in bricks. FA bricks have numerous environmental benefits such as reduced need for CL mining, reduced greenhouse gas emissions, and reduced energy consumption during production. In comparison to CL bricks, FA bricks offer higher CS and reduced efflorescence [6].

In the available literature, numerous research studies investigated the mechanical properties of FA bricks. Tuyan *et al.* [7] reported that a geopolymer brick prepared using waste CL brick powder can obtain a maximum CS of 36.2 MPa by curing at a temperature of 90 °C. Abdullah *et al.* [8] reported that a FA brick comprising CL and FA prepared at 12 M NaOH solution achieved the optimum CS of 70.3 MPa at seven days. Driouchi *et al.* [9] investigated the geopolymer produced with FA and metakaolin. It was observed that mix prepared with 44.7% metakaolin and 32.7% FA achieved a CS of 19.34 MPa, when cured at room temperature without applying molding pressure. Sukmak *et al.* [10] investigated the influence of FA, heating conditions and duration of heat on strength of geopolymer bricks prepared using different combinations of FA and CL. Three different FA to CL ratios of 0.3, 0.5 and 0.7 were investigated. The optimum CS of 12 MPa was achieved with FA to CL ratio of 0.7, after heat curing the bricks at 130 °C for 120 hours and applying molding pressure of 40 MPa. Naganathan *et al.* [11] concluded that the CS was increased with increase in FA content. The optimum CS of 17.4 MPa was achieved.

In the available literature, the studies investigated the mechanical properties of brick mixes with partial replacement of CL with waste material. This study investigates influence of 100% replacement of CL with FA on CS of geopolymer mortar brick mix. To the knowledge of authors, no study has yet investigated the preparation of geopolymer brick mixes without heat treatment and applying molding pressure. The aim of this research is to develop environmentally friendly brick mixes made from FA and CL without heat curing and applying molding pressure.

2. EXPERIMENTAL PROGRAM

This study investigates the effects of varying percentage replacements of CL with FA from 0% to 100% (0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) and curing period (14, 28, 56 and 90 days) on the CS of geopolymer mortar brick mixes using 12 M NaOH solution. To prepare geopolymer mortar mix, CL was sourced from a local kiln in Lahore, Pakistan. The liquid and plastic limits of the CL reported CL to be non-expansive. The Class F FA, grey in color, was sourced from the Sahiwal CPP located in Punjab, Pakistan

A total of 11 mixes were cast and tested. Each mix comprised 12 cube specimens measuring 50 x 50 x 50 mm. The test specimens were cured using wet hessian rugs. Three specimens were tested each on 14 days, 28 days, 56 days and 90 days. The 12 M solution comprised 36% solid NaOH pellets. A ratio of Na_2SiO_3 to NaOH solution was kept as 1.5 for all mixes. The proportions of CL and FA was varied for all percentage replacements of CL with FA as shown in Table 1.

The geopolymer mortar mixes were made by mixing required quantities of FA and CL in a pan mixer for 1 min. The alkaline activator solution and water (4% of FA) was added to the dry mix. The mixture was poured into molds and compaction was performed using vibrating table. The molds were kept at room temperature for 24 hours. After demolding, the samples were cured using wet jute bags for the required number of curing days.

Table -1: Details of mixes prepared with 12 M NaOH solution

Mix	100CL-0FA	90CL-10FA	80CL-20FA	70CL-30FA	60CL-40FA	50CL-50FA	40CL-60FA	30CL-70FA	20CL-80FA	10CL-90FA	0CL-100FA
CL (kg)	2.69	2.42	2.15	1.88	1.61	1.34	1.08	0.81	0.54	0.27	0
FA (kg)	0	0.27	0.54	0.81	1.08	1.34	1.61	1.88	2.15	2.42	2.69

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

This section reports the influences of percentage replacements of CL with FA and curing period on the CS of geopolymer mortar mixes

3.1. Influence of Percentage Replacements of Clay with Fly Ash

The average CS was increased as the percentage replacements of CL with FA was increased from 0 to 100% as shown in Fig. 1. The average CS of test specimens were increased by 111.2%, 39.2%, 37.5%, 0.2%, 19.7%, 26.8%, 19.8% and 1.3%, respectively, as the percentage replacements of CL with FA was increased from 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70% and 70-80%. The average CS were decreased by 2.9% and 4.3% respectively, as percentage replacements were increased from 80-90% and 90-100%. The optimum CS at 14 days and 28 days curing period was achieved at 70% replacement of CL with FA. Similarly, for 56 days and 90 days curing period, the optimum CS was achieved at 80% replacement. The optimum CS of 49.7 MPa was achieved at 80% replacements of CL with FA.

The increase in CS with the increase in percentage replacements of CL with FA was because FA is more efficient precursor for geopolymerization than CL [12]. Moreover, the spherical particles of FA exhibited higher leaching potential, hence more silica and alumina ions were released in the solution and hence increasing the geopolymerization reaction [13]

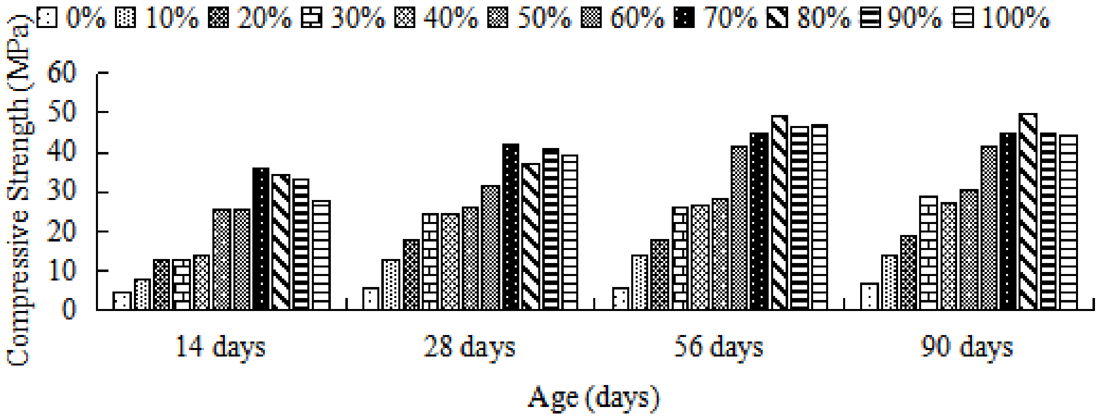

Fig -1: Influence of percentage replacements of clay with fly ash on the compressive strength of geopolymer mortar brick mixes using 12 M NaOH solution

3.2. Influence of Curing Period

The average CS of specimens increased with increasing curing period. The average CS at 12 M NaOH molarity increased as the curing period was increased from 14 to 90 days, as shown in Fig. 2. The average CS of test specimens were increased by 28.9%, 15.3% and 0.9%, respectively, as the curing period was increased from 14 to 28 days, 28 to 56 days and 56 to 90 days. The optimum CS of 49.67 MPa was achieved at 90 days of curing, which was 37.6% (36.09 MPa), 18.1% (42.04 MPa) and 1.1% (49.15 MPa) higher respectively than the average CS achieved at 14, 28 and 56 days of curing periods. The CS of FA bricks increases with increase in curing period, due to the inherent ability of FA to increase its strength over time [14]. Prolonged curing positively affects the increase in CS of geopolymer bricks, due to continuous calcium silicate gel formation, hence CS of bricks increases [15].

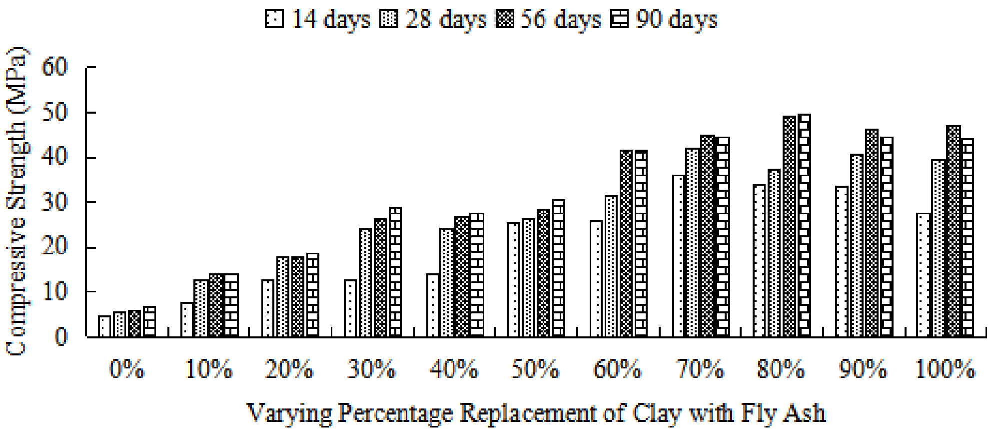

Fig -2: Influence of curing period on the compressive strength of geopolymer mortar brick mixes using 12 M NaOH solution

3.3. Physical and Mechanical Properties of Geopolymer Bricks

The physical and mechanical properties of geopolymer bricks were also investigated. The two mixes i.e. 70FA-30CL and 60FA-40CL with high compressive strengths were selected for physical and mechanical The CS, water absorption, weight per unit area, modulus of rupture (MOR) and efflorescence tests were conducted as per ASTM C67-21 (ASTM 2021). The results indicated that the average CS of geopolymer bricks was 25.6 MPa. The average water absorption rate of geopolymer bricks was 11.1%. The average weight per unit area was 131.7 kg/m^2 and the average MOR was 2.3 MPa. Additionally, the study also investigated the occurrence of efflorescence on geopolymer bricks, which was found to affect less than 10% of the surface area of bricks. As a result, the efflorescence observed was classified as light efflorescence

4. CONCLUSIONS

The aim of this study was to investigate the influences of the percentage replacements of CL with FA and the curing period on the CS of geopolymer mortar brick mixes. The following conclusions were drawn from this study:

1. The average CS of specimens increased with the increase in percentage replacements of CL with FA. The optimum CS was achieved at 80% replacement of CL with FA
2. The average CS of specimens increased with increase in curing period. The optimum CS was achieved at 90 days curing period
3. The optimum CS of 49.7 MPa at 90 days with 80% replacement of CL with FA using 12 M NaOH solution was achieved.
4. The average CS of geopolymer bricks was 25.6 MPa. The average water absorption rate of geopolymer bricks was 11.1% with an average weight per unit area of 131.7 kg/m^2 and an average MOR of 2.3 MPa. Light efflorescence, affecting less than 10% of the surface of bricks was also observed in mixes 70FA-30CL and 60FA-40CL.

The findings of this study have important implications for the construction industry, as FA bricks demonstrate the potential to serve as a sustainable and eco-friendly alternative to traditional CL bricks. By using FA in the production of bricks, it is possible to conserve valuable CL resources, reduce energy consumption, and minimize CO_2 emissions. This, in turn, FA bricks can help to reduce the impact of global warming. This study emphasizes the potential of FA bricks as a sustainable and eco-friendly alternative to CL bricks and highlights the need for more research to fully understand the implications of using FA in construction.

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